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IMPLEMENTATION OF A TWO-USER DISPLAY USING STEREOSCOPICS

by

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The level of presence in a virtual environment depends on the extent to which the real world is shut out, the range of sensory elements the environment simulates, the extent of the panoramic view, and the resolution of the illusion. Many current virtual environment applications effectively address these presence issues for single users, but not for multiple users. Networked virtual environments address multiple user collaboration through real-time interaction of users in a shared environment. These systems provide effective communication between users, but do not address face-to-face collaboration.

To address these needs, this thesis describes a two-user display which fully supports face-to-face collaboration. Each user has independent views of the environment while standing near one another and is able to communicate through voice and gesture. The design of the system includes stereo rendering and magnetic tracking technology. Stereo rendering technology is used to create two separate images that can be viewed independently. A magnetic tracker is used to detect the movement of each user's head. There are drawbacks, including ghosting, that affect the design's usability. Studies are needed to determine appropriate application mediums for this type of system.

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IMPLEMENTATION OF A TWO-USER DISPLAY USING STEREOSCOPICS

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To address these needs, this thesis describes a two-user display which fully supports face-to-face collaboration. Each user has independent views of the environment while standing near one another and is able to communicate through voice and gesture. The design of the system includes stereo rendering and magnetic tracking technology. Stereo rendering technology is used to create two separate images that can be viewed independently. A magnetic tracker is used to detect the movement of each user's head. There are drawbacks, including ghosting, that affect the design's usability. Studies are needed to determine appropriate application mediums for this type of system.

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INTRODUCTION

A. OVERVIEW

Virtual environment technology has become a valuable training tool for the United States military. Billions of dollars have been invested in the development of computerized training devices to assist in training military personnel in war fighting and survival skills. Virtual environments are currently being used for general training, preparation for real conflicts through the use of simulators, and training personnel on the use of new equipment.

Virtual environment systems created for the military have primarily focused on training personnel using various types of military vehicles [Lawson98]. The idea that these virtual battlefields will also allow for safer, less expensive and, in many ways, more flexible training for foot soldiers is gaining attention [Lampton94]. Current virtual environment systems effectively address presence issues for singles users but become less effective in applications involving multiple users. Further development of effective multiple user applications will increase the role that virtual environments play in the military as well as the civilian sector.

B. MOTIVATION

Virtual environment technology is the result of a convergence over many years of several combinations of computer systems, including audio, tracking, and graphical systems. Environments can range from models of real world objects and places to abstract worlds. The level of presence in the virtual world depends on the extent to which the real world is shut out, the range of sensory elements stimulated by the environment, the extent of the panoramic view, and the resolution of the illusion. Many

current virtual environment applications do a good job of addressing these presence issues for single users, but not for multiple users.

Virtual environments employing the use of projection images usually track the head position of a single user. Other untracked users in the environment lose their sense of immersion when the image changes as the tracked user moves. Additionally, virtual objects appear skewed to non-tracked users because they are not viewing the environment from the point of view that it was rendered.

Effective face-to-face collaboration is a common problem in virtual environments. Representations of users, or avatars, have been used to give other users an idea of their location and orientation. This method has met with success but it cannot replace natural expressions and gestures. In many military training situations, such as infantry movement, the requirement for close and even physical contact is vital for realistic training. This realism is not currently possible through the use of avatars.

Direct verbal communication is the most effective type of interaction among people. Often, people use lip motions and hand gestures in conjunction with voice to understand what someone is saying. Facial expressions and hand gestures provide important information that cannot be expressed through voice alone. A single virtual environment system containing avatars for each participant would provide an excellent face-to-face collaborative tool [Agrawala, et. al.97]. Current shared virtual environment systems do not support this type of direct communication among multiple users.

Until technology matures enough to effectively recreate collaboration and direct communication, actual face-to-face interaction is the most successful means of providing effective communication between multiple users. This thesis explores the use of currently

available technologies to create a multiple user virtual environment system that supports face-to-face collaboration.

C. OBJECTIVE

The objective of this thesis is to create a virtual environment application that addresses some of the most common problems associated with current shared virtual environments. Effective collaboration and elimination of distortion is the primary focus. An extension of stereoscopic technology is used to achieve this objective.

The generation of stereo images usually involves the use of two hardware buffers, one for each eye. Images are rendered from two slightly different viewpoints based on the position of the user. Both images are displayed to the user and the user wears special glasses to ensure that each eye only sees its appropriate image.

If each user, instead, wore glasses that allowed them to only see one of the images with both eyes, each user could have their own view of the virtual environment. The concept behind this thesis is to develop such a system and to determine its effectiveness.

D. THESIS ORGANIZATION

This thesis is organized into the following chapters:

- Chapter I: Introduction. This chapter gives a general outline of the work, including the motivation, objective, and the organization of the thesis.
- Chapter II: Literature Review. Technologies related to the research conducted in this thesis are discussed in this chapter. This includes stereo technology and magnetic tracking technology. Collaboration in virtual environments through the use of multi-user environments and networked environments is also discussed.

- Chapter III: Experimentation Platform. Hardware and software used in the design of the system is discussed in this chapter.
- Chapter IV: System Design. This chapter explains in detail the design of the system, from the concept to integration.
- Chapter V: Analysis. Initial impressions of the system are discussed in this chapter. Also lessons learned during the design phase and drawbacks of the system are presented.
- Chapter VI: Conclusions. This chapter renders a final summary of this thesis and describes potential follow-on work.

II. LITERATURE REVIEW

A. TECHNOLOGY REVIEW

The implementation of this thesis requires the use of both stereo rendering and magnetic tracking technology. Stereo rendering technology is used to create two separate images that each can be viewed independently. A magnetic tracker is used to detect the movement of each user's head. This section describes each of these technologies.

1. Stereo Technology

An important consideration when creating a virtual environment application is the level at which the user becomes immersed in the artificial world. Images produced for the user displays frequently appear unrealistic. Images produced using stereo rendering technology have a three dimensional effect, and therefore, have a more realistic appearance. The creation of stereoscopic images simply involves rendering an identical scene from two slightly different viewpoints as shown in Figure 2.1. Each eye receives only the appropriate viewpoint. Natural fusion by the eyes of the two views creates the appearance of three dimensions. There are different methods for rendering and displaying stereo pairs. This section reviews stereo output technologies and viewing systems used in rendering stereoscopic images.

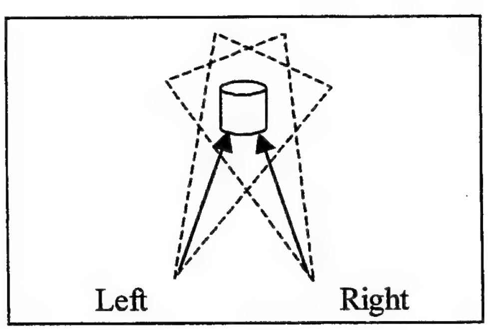

Figure 2.1. Viewpoints of Stereo Images

a. *Output Techniques*

Technologies for producing stereo images can be divided into two broad groups: time-parallel methods, those that present both eye views simultaneously, and time-multiplexed, those that present the left and right views in an alternating fashion.

(1) Time-Parallel Techniques. 3D movies traditionally required the user to wear glasses with red and blue filters. Both images were presented on the screen simultaneously hence it was a time-parallel method. Since the images rarely used the two hues of the lenses, the filters did not completely block the opposite-eye view. This ghosting, or cross talk, is a significant problem. Many observers suffered headaches when leaving the theater, which gave 3D, and stereo in particular, a bad reputation [McAllister93].

A more successful single-display method uses the polarization of light. The left and right images are presented simultaneously, polarized at right angles, and polarized glasses are worn to transmit only the proper image. Ghosting is still an issue, although much less so, and there is no color limitation.

An obvious method to solve the ghosting problem is presenting the images separately via dual parallel displays. Head-mounted displays use this method to display each image to the appropriate eye.

(2) Time-Multiplexed Techniques. A time-multiplexed display alternates between the left and right images, and includes the required hardware to ensure the images reach only the appropriate eye. The most common method of time-multiplexed display is liquid-crystal shutter systems. A signal is sent to the system that

causes one lens to become opaque and the other transparent. The most serious drawback to this type of display method is that the frame rate is cut in half.

b. Viewing Systems

Stereo images are viewed through the use of active or passive viewing systems. Active systems contain the technology to sort out the two images, whereas passive systems use polarized lenses to created the separation of the images to the appropriate eye.

(1) Stereoscopic Viewing Systems Using Active Glasses. Active glasses contain the electro-optical devices that are used to synchronize the two images to ensure that the correct image gets to the correct eye. An obvious consideration with the use of this device is the weight and the obtrusiveness of the glasses, especially for users who wear corrective lenses. Glasses that are connected to a computer by a wire can be a nuisance. Even though the wire can be eliminated with a wireless link, the receiver and batteries in the glasses add weight and volume to the glasses. At the current time, the best compromise seems to be to eliminate the wire and to minimize the receiver weight by using state-of-the-art components [McAllister93].

Another issue is related to the shuttering of the lenses. Each lens is open only 50 percent of the time. The luminance of objects other than the monitor viewed by the user of active glasses will be 50 percent of the luminance perceived by a wearer of passive polarized glasses, and about 15 percent of the luminance perceived by a person not wearing any glasses.

The price of active glasses starts at a few hundred dollars and can go to well over a thousand dollars. Companies such as NuVision Technologies, Inc.

[NuVision00] and StereoGraphics Corporation [StereoGraphics00] produce several types of glasses for a wide variety of 3D viewing applications.

(2) Stereoscopic Viewing System Using Passive Polarized Glasses. Passive polarized glasses are made up of polarized lenses, one that transmits only horizontally polarized light to the eye, and another that transmits only vertically polarized light to the other eye. These glasses address many of the limitations of active glasses. They are lightweight and the luminance of objects other than the monitor viewed by the user of passive glasses is 50 percent greater than users of active glasses. The only consideration when using this device is ghosting or cross talk.

VRex [VRex00], American Paper Optics [American00], and Reel 3-D Enterprises [Reel00] are just a few of the companies that produce passive polarized glasses. The glasses can be purchased for as little as eighty-five cents a pair.

(3) Stereoscopic Viewing System Using Anaglyphic Glasses. Anagylphic glasses are made up of two different colored lenses, typically red and blue. Two perspective images, one of each color, are generated for viewing. When viewed through corresponding colored lenses, the left eye sees only the left image and the right eye only the right image. The brain then combines both two-dimensional images into a single three-dimensional image. The most obvious drawback to these glasses is the color limitation inherent in using the colored lenses.

Anaglyphic glasses can be purchased for less than one dollar per pair. Many of the companies that produce passive polarized glasses also produce anaglyphic glasses.

2. Magnetic Tracking Technology

Magnetic trackers are used to achieve realistic interaction between a user and a virtual environment. These devices allow for the display of the x, y, and z positions and the yaw, pitch, and roll orientations of a tracked object. This section provides an overview of magnetic tracking technology.

a. Description

A typical magnetic tracking device is composed of a transmitter, a receiver, and an electronics unit. The system's capabilities can be expanded by adding up to three additional receivers. The following is a description of each component.

- The electronics unit contains the hardware and software necessary to generate and sense the magnetic fields, compute the position and orientation, and interface with the host computer via an RS-232 port.
- The transmitter contains a triad of orthogonal electromagnetic coils that gives off magnetic fields. The transmitter is the system's reference frame for receiver measurements.
- The receivers also contain a similar triad of electromagnetic coils that detect the magnetic fields produced by the transmitter. The receivers transmit the information to the electronics unit, which computes the position and orientation of the receivers relative to the transmitter. Each receiver is completely passive, having no active voltage applied to it [Polhemus00].

b. Performance

Magnetic trackers are reliable motion capture devices. They are very flexible since they can be attached to almost anything. Transmitters are available that

provide a reasonably large coverage area. Most magnetic trackers are reasonably inexpensive and easy to use.

Magnetic trackers suffer from some drawbacks that effect their accuracy. Electromagnetic interference from electronic devices can cause erroneous readings. Large objects made of ferrous metals can interfere with the electromagnetic fields. Accuracy of the readings becomes less accurate as the distance between the transmitter and the sensor is increased. Latency in some magnetic tracking devices can be a serious drawback in virtual world applications. These delays can cause the user to experience simulator sickness. Minor fluctuations in the magnetic current, the room, etc. can cause a tracker to report motion when none is occurring, causing the object to jitter [Tracker00].

c. Products

There are two main companies that produce magnetic tracker products. Polhemus [Polhemus00], a subsidiary of Kaiser Aerospace and Electronics, produces the *Fastrak*™. Ascension Technology Corporation [Ascension00] produces a magnetic tracker known as the *Flock of Birds*™. The primary difference between the two products is the type of magnetic field they use. The *Fastrak* uses AC transmitters and the *Flock of Birds* uses DC transmitters. Metal objects can cause the AC transmitters of the *Fastrak* to produce erroneous readings. The *Fastrak* has a 120Hz update rate that is divided among its sensors. The use of multiple sensors with the *Fastrak* dramatically slows down the update rate. The *Flock of Birds* 144Hz update rate is the same regardless of the number of sensors attached. A detailed description of the Polhemus *Fastrak* can be found in Chapter III.

B. COLLABORATION IN VIRTUAL ENVIRONMENTS

A collaborative virtual environment is a multi-user application that uses a virtual environment as the user interface. These applications attempt to provide users with a sense of realism by incorporating realistic 3D graphics and stereo sound, creating a sense of immersion for the user.

Effective collaboration is a difficult task in a virtual environment. Attempts to support effective collaboration have resulted in the development of various types of virtual environment systems. Virtual environment enclosures, displays, and networked virtual environments are different approaches that have been developed to increase the ability to collaborate between users and objects in a virtual world, and between different users.

The most difficult form of collaboration to recreate in a virtual environment is face-to-face collaboration. Currently, gestures, such as facial expressions and hand movements, cannot be effectively reproduced in a virtual environment. Until technology can provide this type of realism, applications involving shared single virtual environments are the most effective way to provide face-to-face collaboration.

Many different types of virtual environment systems have been developed to enhance collaboration. This section discusses virtual environment display systems and networked virtual environment systems developed to strengthen collaboration between users.

1. Virtual Environment Display Systems

The goal of a virtual environment is to enable the user to feel fully immersed in the virtual world. The presentation medium used for the virtual world plays a vital role in

the level of presence felt by a user. This section describes display systems that effectively provide visual immersion.

a. The CAVE™

The *CAVE* was developed by Dr. Carolina Cruz-Neira at the University of Illinois at Chicago. The goal behind the *CAVE* was to create a life-size virtual environment enclosure that produced realistic graphic images, giving users a sense of presence in the virtual world. The idea was to get away from the single-user limitations of Head-Mounted Displays. Through the use of projected images, multiple users could immerse themselves in the virtual environment as the same time.

Rear projection screens were used to produce the images on the walls. The walls were constructed from one continuous piece of material, with corners formed by running cable from the floor to above the walls to create the 90^0 angles needed. These wires created a small break in the projection surface and destroyed the stereo effect when objects were projected on them. The structure of the *CAVE* was made of wood to reduce interference for the magnetic tracking equipment.

Stereo images were produced using a time-multiplexed technique and viewed through the use of shutter glasses. Flickering was a major problem due to the low refresh rate. A magnetic tracker was attached to the center of the shutter glasses to track the head motion of one viewer. Acoustical effects were produced using a four-speaker stereo system. The space required to set up a *CAVE* is 35 feet in width, 25 feet in depth, and 13 feet in height for the standard ten foot by ten foot walls [Fakespace00].

The *CAVE* was the first system that supported face-to-face collaboration in that it allowed multiple users to immerse themselves fully in the same virtual

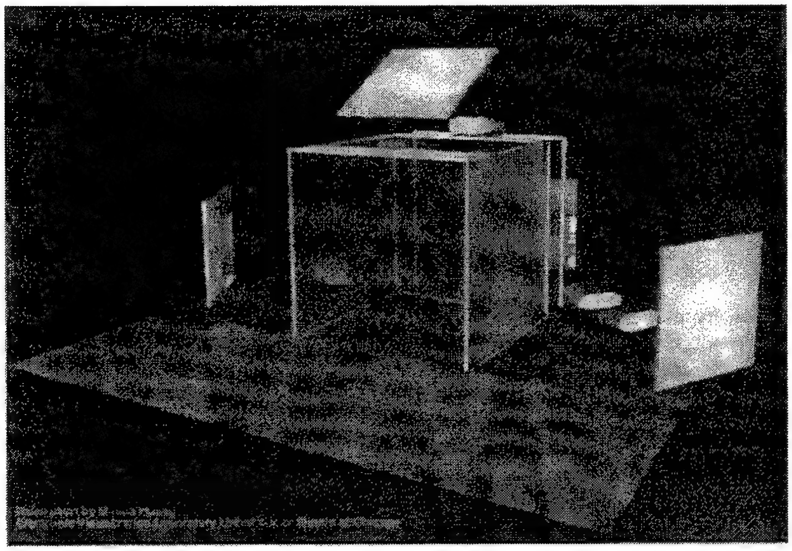

Figure 2.2. Illustration of the *CAVE* [VEE00].

environment as the same time. The main drawback was that only one primary user, causing others the experience distortion in both movement, due to unpredictability, and vision, due to the view being from that user's viewpoint.

b. The C2

The C2 is also a result of research conducted by Dr. Carolina Cruz-Niera. After leaving the University of Illinois at Chicago, she went to Iowa State University and in 1996 developed the C2 [VEE00].

Many improvements were realized with the C2. The most significant improvement was the seamless corners. A clamping system pinched the screen material into an exact 90 degree corner which solved the discontinuity suffered in the *CAVE.* Increased portability came with the use of metal tubing, called Unistrut, to build the support structure. Major improvements in the acoustical performance of the system was also achieved through the use of an eight speaker stereo system. The space required to set up a C2 is 28 feet in width, 21 feet in depth, and 15 feet in height for twelve foot by twelve foot walls [C200].

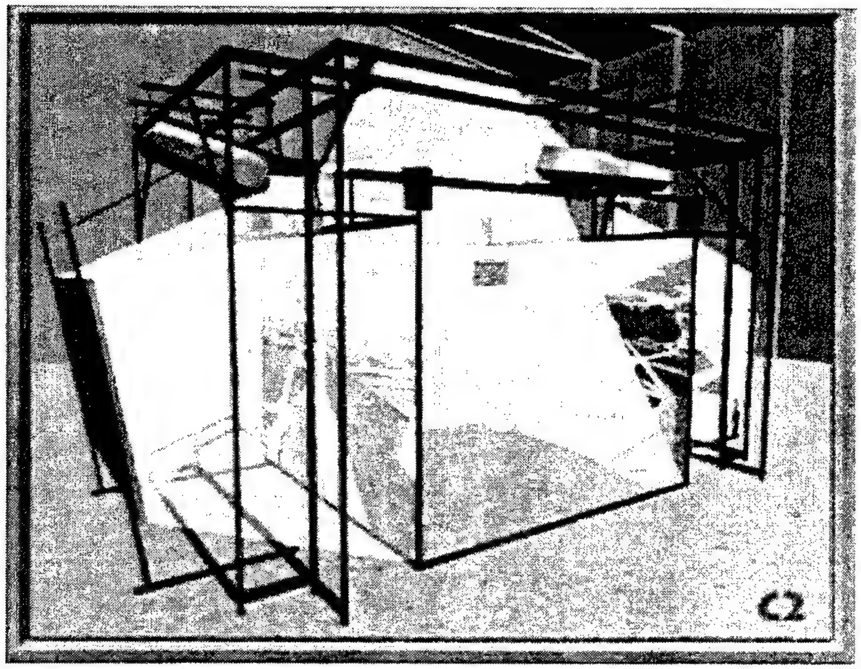

Figure 2.3. Illustration of the C2 [C200].

The C2 was another successful face-to-face collaborative environment. The C2 increased a user's sense of presence in the virtual environment with improvements to the screens and speaker system. The C2 still has the same drawback as the CAVE in that it does not address distortion felt by multiple users of the system.

c. *The CABIN*

The Computer Aided Booth for Image Navigation (CABIN) was developed in 1996 at the University of Tokyo [CABIN00]. The CABIN is a five-walled virtual environment that uses tempered glass for the floor and rear projection material for the three sides and the ceiling. The CABIN is located in a warehouse dedicated solely for its structure. A steel frame provides support due to the extreme weight of the glass [VEE00].

The CABIN went even farther to fully immerse users into a virtual environment with the inclusion of the ceiling and the floor as part of the display. Users'

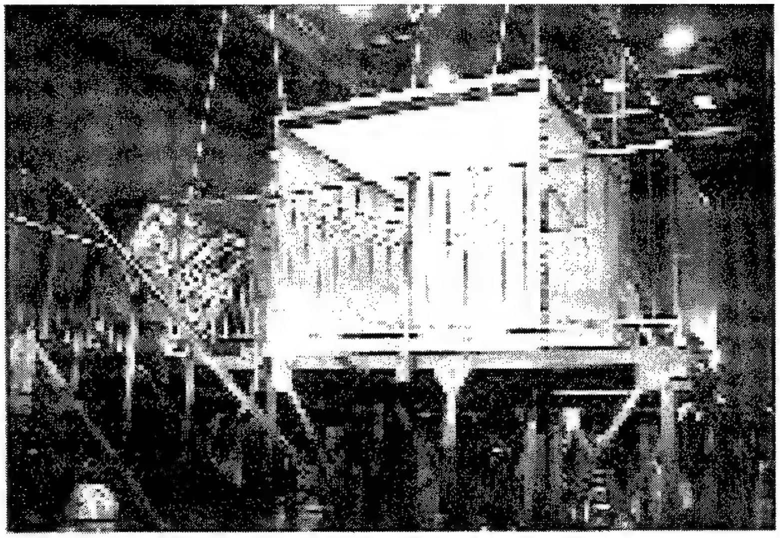

Figure 2.4. Illustration of the CABIN [VEE00].

full range of vision was immersed into the environment. Presence was greatly enhanced for the primary user, but the issue of distortion for other users was not addressed.

d. The Responsive Workbench

The Responsive Workbench is a 3D interactive virtual reality system with a tabletop metaphor originally developed by Wolfgang Krueger at GMD, Germany's National Research Center for Information Technology [Krueger/Froehlich95]. The user of the workbench interacts with the virtual objects on the workbench just as they would with actual objects on an actual workbench.

In order to create the 3D environment, users wear shutter glasses to view the stereoscopic images that are projected onto the tabletop display surface using stereoscopic projectors. The user's head position and orientation are tracked to create the correct perspective when rendering images. An input device is also tracked to allow users to interact with objects on the tabletop environment [Workbench00].

The Responsive Workbench focused on collaboration with objects in a virtual environment. By projecting the object onto a tabletop, users felt a sense of

realism and presence with the object. This system does not address face-to-face collaboration, but is a precursor to the two-user Responsive Workbench discussed later in this chapter.

2. Networked Virtual Environments

Networked virtual environments are systems that allow multiple users to interact with each other in real-time. These systems combine graphics and stereo sound to create a sense of presence in the virtual environment. All users have the illusion of sharing the same space. Collaboration is achieved through the use of avatars and various communication media [Singhal/Zyda99].

The Department of Defense was the developer of a large scale networked virtual environment called SIMNET (SIMulator NETworking). SIMNET uses a software architecture that modeled the world as a collection of objects whose interactions with each other are a collection of events. Individual objects are responsible for placing messages onto the network to accurately represent their current state [Miller/Thorpe95].

NPSNET-IV supported hundreds of simultaneous players, and contained a multitude of avatars [Barham94]. The most recent version, NPSNET-V, is an open-source portable framework that allows run-time inclusion of new entities and behaviors [Capps00].

The Swedish Institute of Computer Science Distributed Interactive Virtual Environment (DIVE) is another networked virtual environment. The primary application of DIVE solved problems of collaboration and interaction. DIVE simulated a conference room for long-distance shared interaction. The virtual environment included 3D human avatars around a desktop inside a room with video and whiteboard walls. The latest

version of the system is called DIVE-3. This version of DIVE supports subjective views and local groups for communication [Carlsson93].

Networked virtual environments give users an immersive experience through the illusion of shared space, presence felt through the use of avatars, and communication, by gesture, voice or typed. Overall, it is an effective collaboration device, but still does not address face-to-face collaborative issues.

C. RELATED WORK

Most of today's virtual environment systems use stereo technology to increase the presence felt by the user through the production of realistic 3D images. The technology itself is unique in that two images are displayed to the user. The concept of this thesis is to use these two images to produce a two-user display that supports face-to-face collaboration and eliminates distortion. Different variations in using these images have been pursued to create two-user virtual environments. This section discusses projects that have evolved using variations of stereo technology.

1. The Two-User Responsive Workbench

The two-user Responsive Workbench is a projection-based virtual reality system that supports tight, face-to-face collaborative interaction between two users [Agrawala, et. al.97]. It allows two people to simultaneously view individual stereoscopic images pairs from their own viewpoints.

The most common display technique for single viewer stereoscopic image displays uses two different frame buffers to store the images computed for the left and right eyes. The two-user Responsive Workbench uses an extension of this approach. Four different frame buffers are used to store each of the images, one buffer for each eye

of each user. Four processors are used to produced each image and custom hardware in conjunction with two graphics pipelines are used to interleave each of the rendered frames.

Modification of the single viewer shutter glasses included an addition to the two standard one eye open, and one eye closed states. A third state in which both eyes are closed is required whenever the images for the other viewer is displayed. The interleaved method used for displaying the images exposed the viewer to an image at every other frame. The low refresh rate caused noticeable flickering.

The main advantage of the two-user Responsive Workbench system is that each user can see a specialized view of the environment. Independent displays of information to a particular user can help to focus their attention to the details of the environment that are important to them. This system fully supports face-to-face collaboration and presents independent views to each user. Problems with the system include a 50 percent reduction in frame rate to each user, obtrusiveness caused by the use of shutter glasses, and the complicated hardware configurations needed to allow the system to work.

2. Bolas' Anaglyphic Stereo System

Another display technique explored with two-user Responsive Workbench was Mark Bolas' Analglyphic Stereo System. Modified anaglyphic glasses combined with shutter glasses are used to present separate views. Users wear individual red and blue filters over each eye, in an opposing fashion to each other [Agrawala, et. al97]. Both users also wear shutter glasses. As the left eyes of the users are exposed, the user with the appropriate colored lens will see their left stereo image. The right eyes are then exposed, and the user with the opposite color lens will see their right stereo image. Each

of the stereo pairs for the first images are then displayed in the same fashion to produce stereo images to each user. Images continue to display in an alternating fashion, producing two different stereo images, viewable only by the appropriate user.

This system also fully supports face-to-face collaboration and eliminates distortion. This technique provides an alternate means of producing two separate stereo images to two different users. The main drawback to this system is the inherent color limitations associated with the use of anaglyphic glasses.

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III. EXPERIMENTATION PLATFORM

A. INTRODUCTION

The experimentation platform that was used in this thesis was primarily determined by what was available for use at the Naval Postgraduate School. The Multiple Angle Automatic Virtual Environment (MAAVE) was under construction during the same timeframe and provided an excellent medium for producing the passive stereoscopic images. Other virtual environment enclosures such as the CAVE, C2, and CABIN would also provide excellent platforms for this experiment. This chapter gives a synopsis of the components used in the system design.

B. HARDWARE

The hardware used in the implementation piece of the thesis includes the Polhemus *Fastrak* Magnetic Tracker, the VRex VR-2210 Stereoscopic Projector, and a virtual environment enclosure called the MAAVE which is located at the Naval Postgraduate School [Christianson/Kimsey00]. This section describes each of these hardware components.

1. Polhemus *Fastrak* Magnetic Tracker

The *Fastrak* accurately computes the position and orientation of a tiny receiver as it moves through space. It provides a dynamic, real-time six degree-of-freedom measurement of position and orientation. The *Fastrak* utilizes a single transmitter and can accept data from up to four receivers [Polhemus00].

The *Fastrak* features include real time measurements, an extended range, multiple receiver capability and multiple output formats. Each feature is discussed further below.

- Real Time - Digital Signal Processing (DSP) technology provides 4ms latency updated at 120 hertz and the data is transmitted to the host at up to 100K bytes/second.
- Range - The standard range of the transmitter is up to 10 feet. Operation over a range of up to 30 feet is possible with the optional Long Ranger transmitter.
- Multiple Receiver Operation - Measurement of up to 4 receivers is possible and up to 32 receivers can be measured utilizing eight multiplexed systems.
- Multiple Output Formats - Positions of the sensors are presented in cartesian coordinates. The orientation of the sensors can be presented as direction cosines, Euler angles, or Quaternions.

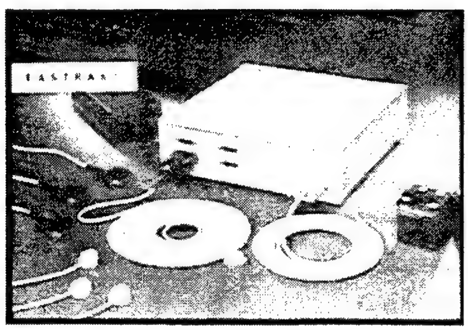

Figure 3.1. Polhemus *Fastrak* [Polhemus00].

2. VREX VR-2210 Stereoscopic Projector

The VR-2210 projector offers full stereoscopic 3D for all viewable positions. Projections of over 7 feet wide with a 140 degree wide viewing angles are possible. The 3D images produced by this projector can be viewed with inexpensive, passive polarized glasses [VRex00].

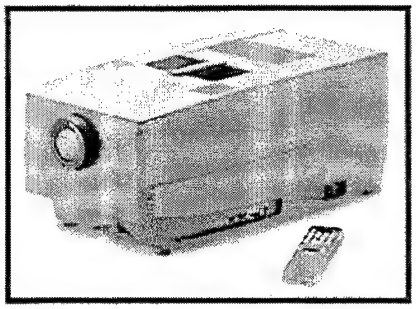

Figure 3.2. VREX VR-2210 Stereoscopic Projector [VRex00].

3. The MAAVE

The MAAVE is the Naval Postgraduate School's version of a virtual environment enclosure. The acronym stands for Multiple Angle Automatic Virtual Environment and was constructed by Brian Christianson and Andrew Kimsey in 2000 [Christianson/Kimsey00]. The MAAVE is a three-walled virtual environment enclosure that uses rear projection screens for each wall. Stereoscopic projectors are used to produce the images on the walls. Each wall is seven feet wide by six feet tall. The physical layout of the MAAVE is shown in Figure 3.3.

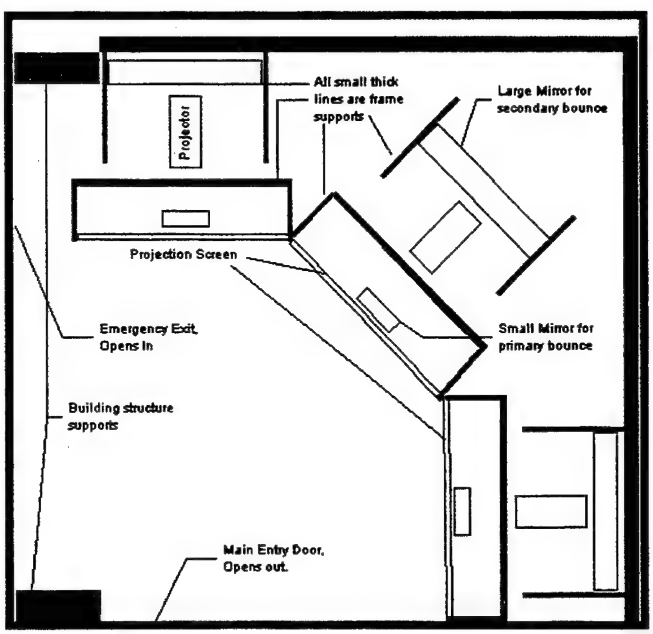

Figure 3.3. The MAAVE Layout [Christainson/Kimsey00].

The MAAVE is powered by an Intergraph personal computer with the following configuration:

- Dual *Pentium*™ II 400MHz processors
- 512 MB RAM
- 3 Intense3D Wildcat 4400 graphics cards

C. SOFTWARE

The software used in the implementation of the two-user display is *VegaNT*™, Version 3.3, a product of Multigen-Paradigm Incorporated. *VegaNT* is a virtual reality programming tool that uses an NT platform. The original version of the software, called *Vega*, runs on a Unix platform. *VegaNT* provides easy-to-use tools for constructing sophisticated virtual environments quickly and easily. It also has stereo capabilities that are used in the implementation process. *LynX*™ is the graphical user interface for preparing and previewing *VegaNT* applications [Paradigm98].

1. An Introduction to *LynX*

LynX is a user-friendly application that makes use of a "windows-like" environment. As shown in Figure 3.4, the graphical user interface of *LynX* is divided into three sections: the icon row, the panel view, and the dockable toolbar and menus. Clicking on a particular icon opens the panel associated with that icon.

2. *LynX* Panels

LynX uses panels that allow for application customization. To the right of the icon column is the panel section. A panel displays the values for a collection of parameters called a class. If multiple instances of a particular class can be created, an instance list is displayed in the upper left hand corner of the panel. The following is a

description of the panels that were customized for use in the thesis implementation. For more information on *LynX* panels refer to the *LynX* Users Guide [Paradigm98].

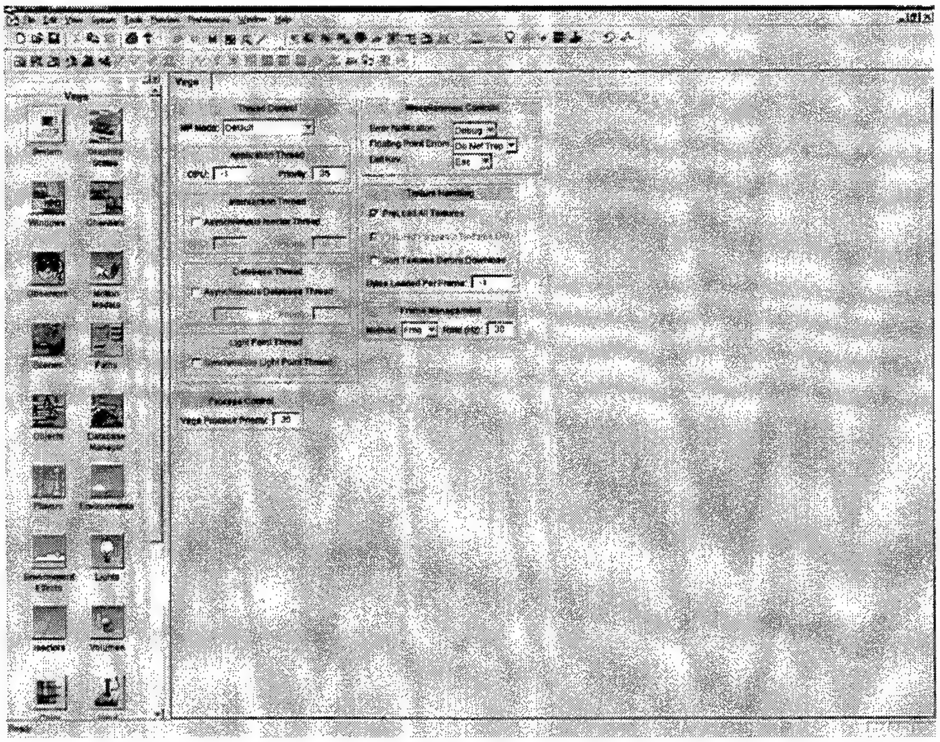

Figure 3.4. *LynX* Window Layout

a. Channels Panel

A channel defines an individual view into a scene. Multiple channels can be defined for a particular window. At least one channel must be defined before scene viewing can occur. The channel position establishes the physical location of the channel within the window. Viewing parameters such as the viewing volume, frustum, skew, and culling can also be adjusted in this panel.

b. Input Devices Panel

This panel allows for the creation and management of input device class instances. An input device class communicates with motion models and observers. The

default input device instantiation of *LynX* is the mouse. Parameters that can be customized include the device type, device file name, baud rate, device scaling and read method. The Polhemus *Fastrak*, which is used in the implementation, is included among the list of input device types.

c. Motion Models Panel

A motion model is the way an observer moves through the scene. This panel allows for the creation and management of motion model class instances. There are many predefined motion models that are inherent to the *LynX* software. One of the motion models, Input Device Direct, gets its position updates from an input device. This model used in the implementation to get the position of the Polhemus *Fastrak*'s receivers.

d. Observers Panel

An observer is required for viewing a scene. It can be compared to a movie camera or sensor positioned in the scene. A scene must be specified before the observer can see anything. A single observer can be used to control multiple channels. An observer can be positioned in six different ways. The positioning model used for the implementation is the Motion Model. This selection allows for the use of a motion model instances created in the Motion Models Panel.

e. Players Panel

A player represents a dynamic entity within the simulation that may be positioned, oriented, and controlled by the user. Player positions are specified as either absolute world coordinates, or as coordinates relative to a specified observer, player, or arbitrary coordinate system. There is no limitation of the number of players that may be

added to the simulation, although quantities are typically based upon the machine capacity and performance goals.

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IV. SYSTEM DESIGN

A. BASIC CONCEPT

As stated in Chapter I, the primary focus of this thesis is to develop a way for two people to interact with the same virtual environment simultaneously. Stereo images are normally displayed by using one known position. Each image displays the view at slightly different angles to the left and the right of the position based on eye separation and convergence parameters. If instead, each image had its own position, different views of the same scene would be produced and rendered to the display simultaneously. This concept is used to create a two-user display.

In order for different views to be displayed, the position must be changed for each image just before it is rendered. Each image position is determined from the position of the two Polhemus *Fastrak* receivers. The left and right stereo buffers are used to store each viewing image. Current positions are obtained and the each viewing frustum image is placed in the appropriate stereo buffer. Both buffers are then displayed for viewing.

Each user is restricted to viewing only one of the images by wearing special polarized glasses that only contain either the left or right viewing lens for both eyes. A description of the system design used for this thesis is provided in the next section.

B. DETAILED SYSTEM DESIGN USING *LYNX*

The idea is to create two monoscopic views of the scene using stereo buffers. Each buffer will contain an independent viewpoint into the scene. The placement of each viewpoint will be based on the position of separate receivers on a magnetic tracker. Both images are rendered to the display in the same fashion as normal stereo images. Each user wears special polarized glasses that allow only a single image to be viewable.

1. Producing Individual Views Using Stereo Buffers

The first challenge of the system design is splitting the stereo images for independent viewing. Applications that support stereo imaging use two different frame buffers to store the left and right viewpoints. The viewing position of both images is determined from the position of the user. The left image viewpoint is rendered to the left of the user's position based on eye separation and convergence parameters. The right image is rendered in a similar fashion. In order to present independent views, the position of each buffer image must be changed to the position of each of the two users before it is rendered for display.

As stated in Chapter III, *LynX* is the software application used in the system design. Earlier versions of *LynX* did not include the capability to choose the left or right buffer for viewing. Selecting stereo enables both images to be produced using a single position. The only way to change the image positions is to generate code, called a callback, to execute in conjunction with the application. Callbacks manipulate data just before each frame is rendered. Inserting code to change the position of each image will create independent views of the same scene.

The latest version of *LynX* actually makes the task of splitting the stereo images quite easy and coding is not necessary. In order to split the two stereo images, two channels are created using the Channels Panel. As shown in Figure 4.1, the Stereo Buffer box contains options that allow for the selection of a single buffer. The "left only" is selected for one channel and the "right only" is selected for the other channel. Each of these channels represents one user's view of the scene.

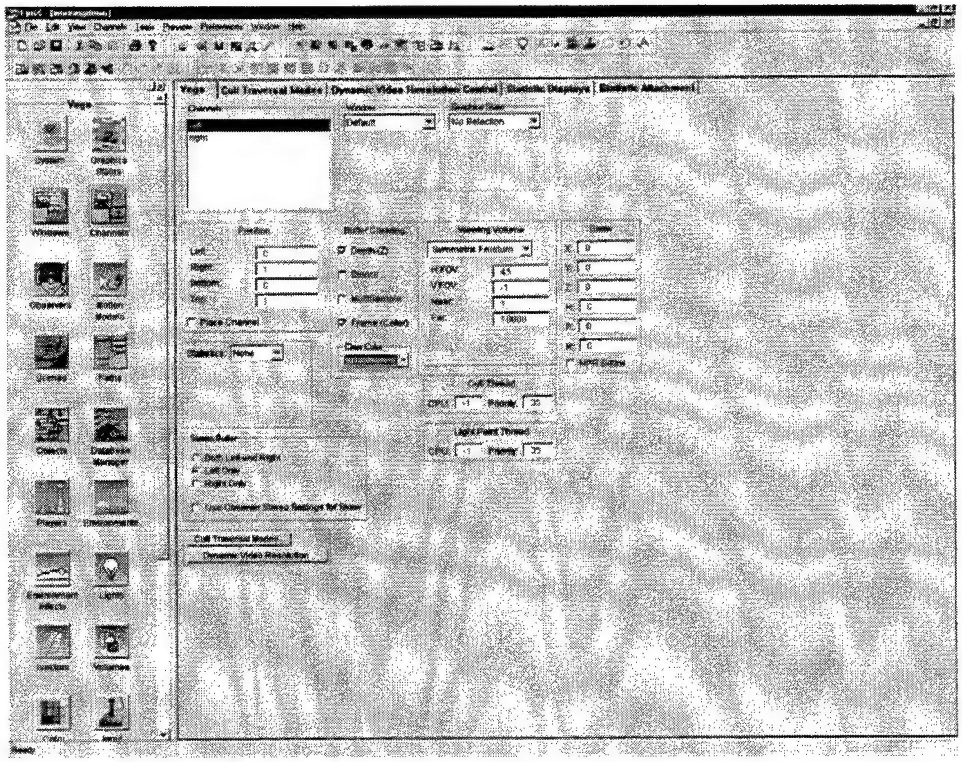

Figure 4.1. *LynX* Channels Panel

Two observers must be implemented in order to view each of the channels, using the Observers Panel. The observers are assigned to each channel by selecting the appropriate channel in the Channel box, as shown in Figure 4.2. The creation of an observer for each of these channels accomplishes the task of producing individual views using stereo buffers.

2. Incorporating the Magnetic Tracker for Motion Detection

Now that two independent views of the scene have been created, the next challenge in the system design is enabling each user to have independent movement in the scene. The implementation for this design requires each user to look around the scene. Since head motion detection is needed for each user, the Polhemus *Fastrak* with two receivers attached is used to track each user's head movements. Support for the

Polhemus *Fastrak* is included in *Vega/LynX*. An input device is created for each receiver in the Input Devices Panel. Each receiver is attached to one of the observers as the HMD Input Device. Each observer represents the head movement of the users.

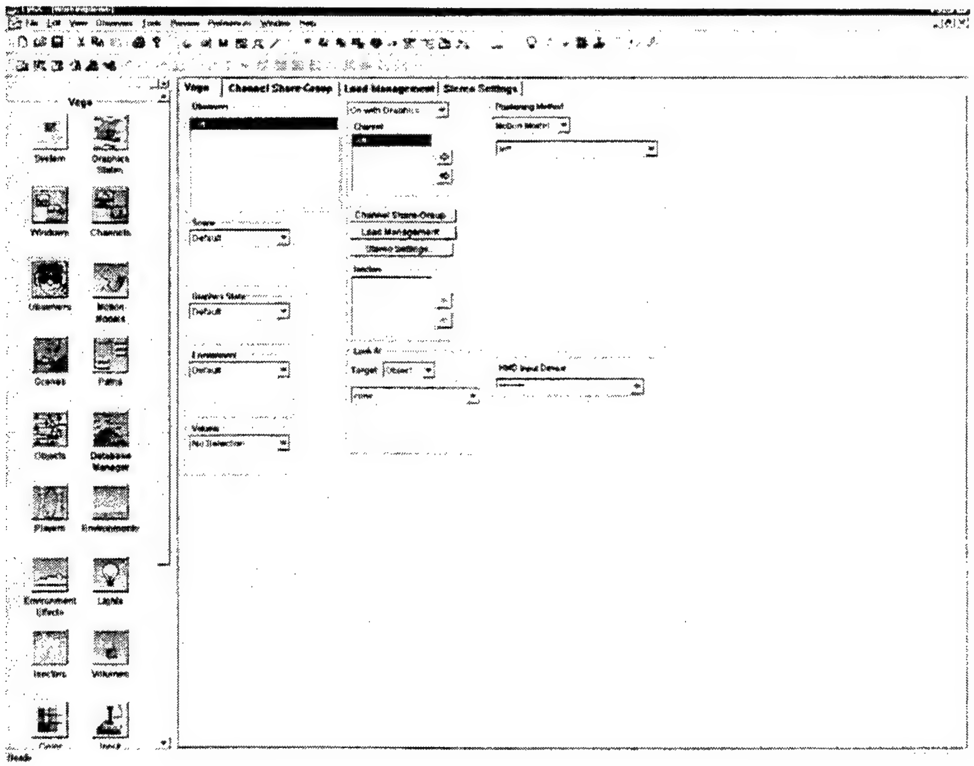

Figure 4.2. *LynX* Observers Panel

Movement through the scene is accomplished by establishing players. By using the HMD Input Device option when creating the observers, each observer is now allowed to follow a player. Two players are created using the Players Panel. Figure 4.3 shows how each player is attached to an observer by selecting them in the Coordinate System box of the Players Panel. The players created serve as tethers to the observers and represent the movement through the scene. Each player's motion depends on the positioning method selected. Two views of the scene with independently controlled movement are now possible.

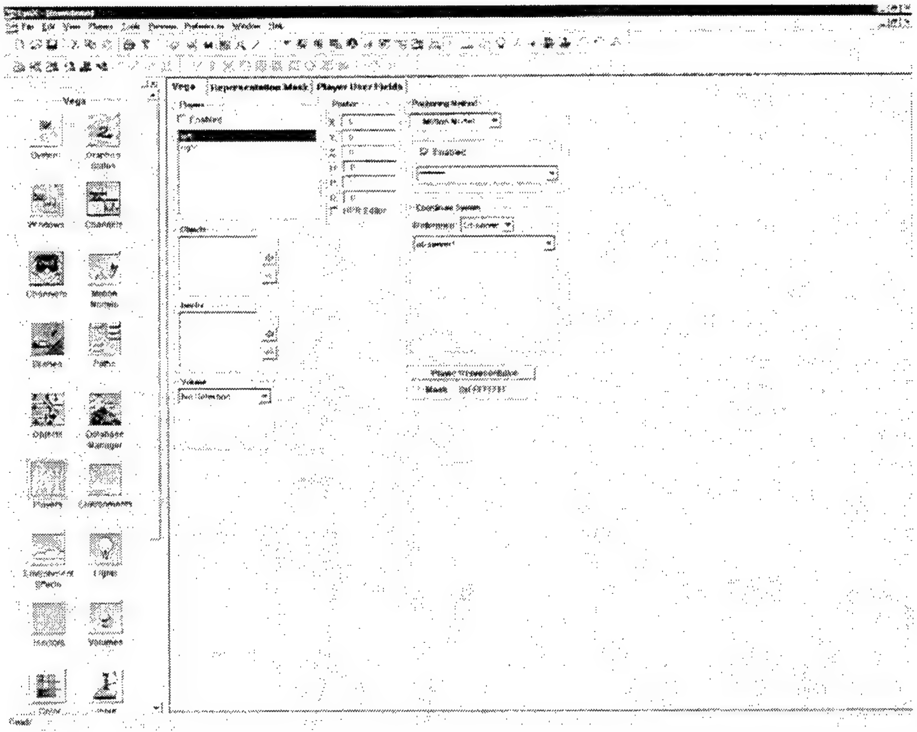

Figure 4.3. *LynX* Players Panel

3. Creation of Modified Passive Glasses

Now that the two-user display has been created, the next task is to ensure each user views only the appropriate image. The simplest, but impractical, way of viewing only one image, is to close one eye while wearing stereo glasses. Another method would be to block one of the lenses on the glasses, which, again is not practical because it is not natural for a person to see from only one eye. A third solution consists of modifying active glasses, alternating images every frame while limiting a viewer one set of images.

The method selected was to create a pair of passive polarized glasses that contain lenses that are alike. Since passive polarized glasses are inexpensive and made of plastic, these modified passive glasses were created by cutting two pair of glasses in half and reattaching the like lenses together. Users wearing these special glasses view either the left or the right buffer image, depending on which set of glasses they have.

C. IMPLEMENTATION

The implementation involves both users moving through a scene in unison. Each user has the ability to look around the scene independent of the other. The combined movement through the scene is controlled with a mouse. Each user's head motion is detected through the use of a magnetic tracker with two receivers attached, one to each viewer.

Initially, a scene must be created for viewing. The focus for this thesis was not on the scene, but rather on the concept of creating a two-user display. The test was a single object. Once full functionality of the system was achieved, a detailed scene was added. The scene used in the application is a town demonstration that comes with *VegaNT*'s software package. The scene is applied to the application by attaching the file to an object in the Objects Panel and then added to the scene using the Scenes Panel. The remainder of the application is set up using *LynX*.

For developers who choose not to use an application to set up the virtual environment, the following pseudocode is provided:

- Device Initialization

`ReceiverName = NewInputDevice();`	*Create a new input device*
`SetInputDevice(ReceiverName, Port);`	*Set port for device*
`SetProperty(ReceiverName, DeviceType,BaudRate, Sychronization);`	*Set properties such as device type, baud rate, and synchronization*

Figure 4.4. Pseudocode for the Initialization of a Polhemus *Fastrak*

- Retrieval of Position Data

`OpenDevice(ReceiverName);`	*Open device for input*
`PositionName=NewPosition();`	*Create a variable to store position data*
`GetPosition(ReceiverName, PositionName);`	*Retrieve current position data*

Figure 4.5. Pseudocode for Retrieving Current Position Data

- Image Display

`InitDisplay(STEREO);`	*Initialize display to include stereo*
`While(true):`	*Infinite loop to continuously render frames*
`GetPosition(ReceiverName, PositionName);`	*Retrieve position of receiver1*
`DrawBuffer(left, PositionName);`	*Draw viewing frustum from position1 into left buffer*
`GetPosition(Receiver2Name, Position2Name);`	*Retrieve position of receiver2*
`DrawBuffer(right, Position2Name);`	*Draw viewing frustum from position2 into right buffer*
`DrawFrame();`	*Display left and right buffers*
`EndWhile;`	*End of infinite loop*

Figure 4.6. Pseudocode for Displaying Both Images

D. SYSTEM INTEGRATION

The MAAVE is an ideal platform for the implementation of the design application. It is powered by an Intergraph dual *Pentium*™ II personal computer. The MAAVE's stereoscopic projectors provide the ability to produce passive stereo images that can be viewed with polarized glasses.

The town scene provides an excellent platform for the two-user display system. Both users move through the scene together, each with the ability to look around. The

implementation rationale is equivalent to two people riding in a car with the ability to look around and talk about the scenery around them.

V. ANALYSIS

A. INITIAL IMPRESSIONS

The clarity of the individual views is better than initially thought. Some minor ghosting is apparent but does not make the system unusable. In fact, during informal tests with the single object, some users did not notice any ghosting. Ghosting is more apparent with the detailed scene, but it is not overwhelmingly distracting. The ability to have face-to-face collaboration with another user about their view of the environment makes this design very effective. Overall, the system design met its expectations.

B. DRAWBACKS

Even though the design proved viable and useful for many applications, there are some noticeable drawbacks as noted below.

- Monoscopic Viewing: Providing only monoscopic views to each user instead of stereoscopic images is probably the worst drawback of the system. Virtual environment applications that require stereoscopic depth information cannot be supported using this system.
- Head Positioning: When using the system, a user's head must stay reasonably level for the clearest viewing. If a user leans their head away from horizontal, the other image comes into view. This is due to the way the angles are cut in the lenses of the passive polarized glasses. Since the polarizations differ by 90^0, leaning 90^0 produces the other view. Viewing the display with head leaning of less than 45^0 minimizes distortion caused by this problem.
- Ghosting: Although ghosting was minimal with the test application, it became more apparent when using the detailed scene. Ghosting of darker objects

could been seen on the lighter colored objects due to the dominance of the darker color over the lighter color. The ghosting causes some distraction for users, but it does seem to become less bothersome as users became accommodated to the environment.

- Limited Movement: Using the short-range transmitter of the *Polhemus Fastrak* allows only limited movement for the users. Due to many metal objects in and around the MAAVE structure, jitter becomes noticeable from only a couple of feet away.
- Users Not Fully Independent: Each user cannot move through the scene individually. Both users' movements are controlled by a single mouse. This problem can be easily resolved by attaching a separate movement device to each image.

C. LESSONS LEARNED

As with any research project, there are many ideas that seem to make sense but turn out to be dead ends. There are also other things that, in retrospect, seem like obvious things to consider, but were not addressed. Some of the lessons learned while completing this thesis follow:

- Stereoscopic projectors should be fully optimized before conducting tests using stereo images. The initial setup of the projectors included two segments of video cable running between the projectors and the computer. The clarity of images was effected by the use of two cables. By moving the computer into the MAAVE and using only one cable for the projectors, the clarity of the images greatly increased.

- The lenses of polarized glasses cannot be turned around and expected to produce the same image view. Simply cutting two pair of glasses into two halves and gluing the like lenses together by turning one of them around will produce glasses with opposite lenses. Due to the way the angles cut in the lens of polarized glasses, turning them around in effect gives you the opposite lens.
- The primary objective of this thesis was to create a virtual environment application. Including a simple study using the application would have given the application more credibility.

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VI. CONCLUSIONS

A. SUMMARY

Today's advances in technology have allowed virtual environment applications to enhance and, in some cases, replace traditional ways of accomplishing tasks. Attributes, such as the level of presence felt and the ability to collaborate, determine the effectiveness of these systems.

Stereo technology was developed to generate a sense of realism in the environment. Virtual environment enclosures have successfully increased presence felt by individual users, but are limited in that only one user has control of the environment. Networked virtual environments address collaboration by providing real-time shared virtual environments for multiple users. Avatars are used to facilitate collaboration but are not as effective as face-to-face collaboration.

The two-user display created for this thesis fully supports face-to-face collaboration. Each user has their own individual view of the environment while standing near one another and are able to communicate through voice and gesture. Perspective distortion of the images is eliminated because each view is rendered from the user's point of view and because each user's head motions control movement. The effect of this technique on presence can only be determined through studies conducted using this system in specific applications.

There are some drawbacks that may effect the system's usability. The inability to view stereo images may be the most detrimental. Ghosting and head movement restrictions are other problems that are realized with this type of system. Studies are

needed to determine what applications would be appropriate for this type of system, given these drawbacks.

B. FUTURE WORK

1. Enhancements

A few minor improvements to the system design would greatly enhance its performance and make it useful for future research projects and demonstrations. The following suggestions are recommended as improvements for the system:

- Individual Movement of Users: The use of two input devices to control each user would fully demonstrate the concept of independent views of a scene.
- Manufactured Specialized Glasses: Manufactured passive polarized glasses with identical lenses would present a more professional appearance and increase durability.
- *Long Ranger*™ Transmitter: Polhemus *Fastrak*'s long range transmitter would increase the mobility of the users.

2. Studies

There are many areas of analysis that surface with regard to this system. Determining the effects face-to-face collaboration has on the level of presence felt by users should be studied. Analysis of the feasibility of two users interacting while viewing the same environment would help determine the credibility of the system design.

Studies analyzing the usefulness of creating specialized views to different users could also be conducted. Each user would have specialized views of the environment. Models could be layered and only relevant parts of the model would be presented to each user. Both users could focus on a certain portion of the model and verbally collaborate

by discussing their individual views with each other. The effectiveness of these collaborative interactions using these specialized views could be analyzed.

Usability studies examining the drawbacks of the system should be conducted. Ghosting and the lack of stereo capability obviously are detrimental with many applications. Models of various detail, color schemes, etc., could be analyzed to determine the relationship between various types of models, levels of ghosting, and the effects ghosting has on the user. These studies could determine the appropriate types of applications that would be suitable for use with this system.

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